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**PLASMA ARC/SCWO SYSTEMS FOR WASTE-TO-
ENERGY APPLICATIONS UTILIZING MILWASTE
FUELS**

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General Atomics

**JULY 2013
Final Report**

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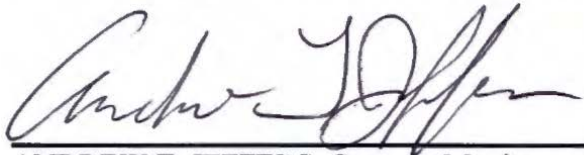
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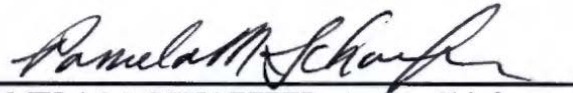
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1. SUMMARY

Contract FA8651-04-C-0158 focused primarily on the Vitracycle program and the development program for advanced supercritical water oxidation systems.

The Vitracycle program was a research and development program aimed at developing a solid waste treatment technology to compliment General Atomics' (GA's) existing supercritical water oxidation (SCWO) technology. While SCWO is for the treatment of liquid wastes, Vitracycle was designed as a treatment technology for solid wastes. GA partnered with Asian Pacific Environmental Technologies (APET) to develop a plasma arc vitrification (PAV) system to process solid wastes. APET already owned and operated a PAV system to destroy medical wastes; however, the system never provided reliable and energy efficient operation. As a result, APET wanted GA to redesign their waste treatment facility. GA assembled an engineering assessment team to investigate ways to improve plant reliability and to improve power consumption and possibly implement power production from the gasification of the medical waste. After the team evaluated the existing APET plant, it was decided that GA would redesign the vitrification reactor and move away from plasma arc technologies. GA came up with its own unique vitrification technology and named it Vitracycle. The Vitracycle equipment was designed, fabricated and shipped to GA in San Diego. The Vitracycle program was incrementally funded with congressional funds. The program was funded through the design phase; however, a third round of funds was necessary to install and test the equipment. Unfortunately, Congress did not approve additional funding. The Vitracycle equipment was never tested and the program was never completed. The equipment was placed into long term storage.

The second element of this contract with the Air Force was to continue to develop advanced supercritical water oxidation systems. GA was funded to design and build a 3 gallon per minute (gpm) industrial SCWO (iSCWO) system to be installed and operated in Alaska. GA partnered with Pacific Environmental Corporation (PENCO) for this project. PENCO would build and operate a Resource Conservation and Recovery Act (RCRA) permitted hazardous waste treatment facility in Alaska. GA would help PENCO install an iSCWO system and permit it at their waste facility. GA and PENCO began the permitting process but never completed this task due to funding issues. GA did complete the design and build of the iSCWO system for Alaska. Although there were insufficient funds to complete the construction and permitting of a waste facility, there were enough funds remaining on contract to perform demonstration tests with the iSCWO equipment. With Air Force approval to change the statement of work for the contract, GA used the remaining funds on the contract to install the iSCWO system at Explo Systems at Camp Minden in Louisiana. Explo Systems had an existing RCRA permit for their facility at Camp Minden. Explo applied for and received a permit modification to the RCRA permit that allowed them to operate an iSCWO system for hazardous waste destruction. GA completed a series of demonstration tests at Camp Minden using the iSCWO system. GA was able to process a simulant waste stream and several energetic slurries containing ammonium perchlorate, hexachloroethane and ammonium picrate. The simulant and the energetic waste streams were completely destroyed and the liquid effluent met all test objectives.

2. INTRODUCTION

This final report is intended to summarize the work performed by GA during the life of contract FA8651-04-C-0158 with the AFRL. The contract was initiated and project activities began in April 2004. All work performed on this contract is under GA Project Number 30217. The primary goals of this contract were to research and develop gas vitrification technologies and to develop, demonstrate and commercialize SCWO technology in Alaska. Tasks under this contract included:

- Plasma Arc Power Generation Design Tests
- Plasma Arc Reactor Design Tests
- Plasma Arc Demonstration
- Advance SCWO Demonstration

3. ACTIVITY SUMMARIES

3.1. Development of Vitracycle

Development of the Vitracycle technology for the treatment of solid wastes initially came about as a research and development project into plasma arc technology. GA was initially approached by APET, a Hawaii based company, to evaluate their Plasma Arc Vitrification Medical Processing Facility built on the Island of Oahu. The APET PAV facility was designed to process medical waste. It was advertised as a net positive energy system meaning the designer claimed that the system could destroy medical waste via vitrification and plasma arc to produce a syngas, which could then be burned in a bi-fuel generator to produce electric power to run the plant and to also sell power back to the electric company. APET purchased the design and build of the PAV from another party. Realizing that the PAV was not reliable or net energy positive, APET partnered with GA to evaluate and possibly redesign the facility.

3.1.1. Plasma Arc Power Generation Design Tests

In June 2004, a GA team of engineers visited the APET PAV facility to evaluate and study the process. The GA team included engineers with experience in process design, controls, power systems and plasma arc technologies. The goal for the team was to evaluate the plant and to come up with a report recommending plant improvements, which could be implemented to make the plant reliable and a viable technology. During their visit, the GA engineering team documented the plant operations, recorded data, collected samples, and interviewed plant personnel.

Following the site visit, GA began writing an engineering assessment report for the APET PAV site, GA Doc. No. 302171902 Rev. NC (Ref. 1). The report compiled the findings from the site visit with information gathered from discussions with equipment manufacturers, sample analysis, data analysis, and the results of a mass and energy balance calculation. The process and equipment capabilities were then compared to the design requirements and the findings of the mass and energy balance calculations. GA then began a literature study to identify ways to improve plant performance. The results of the study were presented in the engineering assessment. A summary of the findings from the engineering assessment are presented below:

- According to the theoretical mass and energy balance calculation for the APET PAV system, the process cannot be net energy positive. The APET PAV facility consumes 160 kW of energy while it can only generate approximately 140 kW of energy from burning syngas generated from the pyrolysis of medical waste
- The PAV reactor generates a significant amount of fine carbon powder which is high in energy value and could be used to heat the vitrification reactor thus eliminating the electrical heating elements used to heat the vitrification reactor
- Eliminating the electrical heating elements in the reactor could reduce electrical power consumption of the APET plant by 80%
- GA recommends replacing the PAV reactor design with a GA designed reactor, which uses a carbon lance to heat the vitrification bath. The carbon lance would burn the fine carbon generated during the pyrolysis of medical waste to heat the process

3.1.2. Reactor Design Tests

Based on the findings of the engineering team, GA began to design its own vitrification pyrolysis system to eventually replace the APET PAV system. GA began to focus on six main areas of research for their pyrolysis system design. These six categories are as follows:

1. Feed systems
2. Patents, blast furnaces and GA reactor designs
3. Plasma arc systems, plasma arc power supply, configuration and physics
4. Gasification and pollution abatement systems
5. Slag chemistry, refractory design, and glass and metal pouring
6. Energy recovery

After literature design studies, GA decided to model their reactor design after iron ore blast furnaces, which have many of the same operating parameters and issues encountered by vitrification reactors.

The GA pyrolysis system design was started in the fall of 2004. GA began procurement of Vitracycle components in late 2004 and early 2005. Table 1 lists the components procured and the name of the manufacturers.

Table 1. Vitracycle Component List

Component Name	Manufacturer	Description of Component
Bi-fuel generator	Energetech & GTI	Generator designed to run on syngas and diesel fuel to generate electrical power
Carbon lance	Process Technology Inc (PTI)	Carbon lance designed to burn fine carbon to heat the internals of the Vitracycle reactor including the molten glass bath
Reactor	JT Thorpe	Carbon steel refractory lined reactor system with a removable top head and a carbon hearth bottom
Syngas compressor	SIHI Pumps	Pressurizes syngas and delivers it to the bi-fuel genset
Syngas processing system	Bundy Environmental Technology	Evaporative cooler, bag house and scrubber designed to cool the gas effluent, to separate the carbon dust from the gas effluent and to scrub out acidic gases from the syngas

In addition to the procurement of process components for the Vitracycle system, GA also designed and procured ancillary components to support pilot testing at GA. Ancillary components procured are listed in Table 2.

Table 2. Ancillary Component List

Component Name	Manufacturer	Description
Electrical resistance system	Simplx	Load cell for bi-fuel genset
Gas analyzer	Siemens	On-line gas analyzers for carbon monoxide, carbon dioxide, total hydrocarbons, hydrogen, oxygen, and hydrogen sulfide
Gas flare	NAO Systems	Gas flare to burn unused syngas
Plant air compressor	Ingersoll Rand	Plant air for the operation of instruments and to convey carbon powder from the bag house to the carbon lance
Reactor vessel platform	Ries Construction	Tri-level super-structure built to support the Vitracycle reactor, piping, carbon lance and feed system

During construction of the Vitracycle system, GA had intended to run pyrolysis tests at the APET PAV facility to gather additional data points for the final design and operational parameters of the Vitracycle system. However, in order to run tests at the APET facility, their vitrification reactor required much needed maintenance and upgrades. GA agreed to re-line the APET reactor with a new refractory system similar to the GA Vitracycle refractory design and a new molten bath pouring system was to be installed on the APET reactor. These upgrades and maintenance activities were started but never completed by APET because the actual costs exceeded the budgeted costs and a stop work was issued by GA to APET to prevent a cost overrun. GA informed APET that these cost overruns were unacceptable and GA would not increase the APET funding to account for the overruns. In addition, GA was informed by APET that they were having possible patent infringement issues with the designer/manufacture of their PAV facility, InEnTec (IET). As a result, a suit/countersuit between APET and IET emerged and GA decided to drop the use of the APET facility from its program plan and decided to focus primarily on the design and construction of the Vitracycle system.

Installation of the Vitracycle equipment and ancillary systems began in December 2005 with the construction of the reactor vessel platform at GA. Installation of major Vitracycle components were completed in March 2006. Final assembly of the Vitracycle system including installation of interconnecting piping between the reactor, the syngas processing system and the genset was never completed because FY06 funding was never approved for the project. Much of the process instrumentation was not installed and remained in storage at GA. Table 3 lists the Vitracycle components and ancillary systems installed at GA.

Table 3. Vitracycle Equipment Installed at GA

Component Name	Description	Location at GA
Reactor support structure	Tri-level super-structure designed to support the Vitracycle reactor, piping, carbon lance and feed system	Inside Building 36
Reactor	Carbon steel, refractory lined reactor	Inside Building 36
Syngas processing system	Evaporative cooler, bag house and scrubber designed to cool the gas effluent, to separate the carbon dust from the gas effluent and to scrub out acidic gases from the syngas	Inside Building 36
Carbon lance	Burns carbon in a lance to provide heat to the Vitracycle reactor	Inside Building 36
Syngas compressor	Pressurizes the syngas generated from the Vitracycle process and sends it the bi-fuel generator	North side of Building 36
Gas Flare	Gas flare to burn unused syngas	North side of Building 36
Electrical resistance system	Load bank for the bi-fuel genset	North side of Building 36
Bi-fuel genset	Generator designed to run on syngas and diesel fuel to generate electrical power	North side of Building 36

Since assembly was never completed, checkout and systemization testing of the Vitracycle system was never started. Unfortunately, additional funding was never approved and the Vitracycle program was mothballed (CLIN001 and CLIN002).

3.2. Industrial Supercritical Water Oxidation (iSCWO)

In addition to developing a pyrolysis technology on this contract, GA was funded to demonstrate an advanced supercritical water oxidation system. For this effort, GA partnered with PENCO. PENCO is an emergency response clean-up contractor specializing in oil spill response, preventative booming, sub-surface oil recovery, hazardous materials response, tank cleaning and waste brokering. PENCO has offices in Honolulu, Hawaii and Anchorage, Alaska. GA was funded in October 2006 to do the following:

- Design and build an advanced 3-gpm iSCWO system
- Assist PENCO in selecting a site to build a hazardous waste facility
- Assist PENCO in identifying wastes generated in Alaska that can be processed by SCWO
- Assist PENCO in obtaining environmental permits to build and operate a RCRA permitted hazardous waste treatment facility in Alaska
- Support PENCO in the design and construction of a hazardous waste facility
- Install the iSCWO system in the RCRA permitted facility owned and operated by PENCO
- Train PENCO to operate and maintain the iSCWO system during iSCWO demonstration testing

3.2.1. Design and Build an Advanced Industrial Supercritical Water Oxidation (iSCWO) System

Design and fabrication of the iSCWO system for Alaska began in December 2006. Unlike previous SCWO systems, which were all completely assembled in house, GA decided to have the Alaska system fabricated and partially assembled by Separation Engineering Incorporated (SEI), an original equipment manufacturer (OEM) company. Custom-built equipment was fabricated by various manufacturers then shipped to SEI where they were skid mounted and electrically wired to the control system and electrical panels. Table 4 lists the major pieces of equipment and where they were manufactured.

Table 4. List of Equipment Manufacturers

Equipment Description	Manufacturer
Equipment skid and electrical	Separation Engineering Incorporated
Gas fired heater	Dayco
Gas liquid separator (GLS)	Lortz Manufacturing
Heat exchanger	Heat Exchange
High pressure air compressor	Greenfield Compressors
Reactor	TSM

SEI was also responsible for designing and welding the equipment skid. SEI also ordered and installed all of the electrical pumps, motors, electrical panels, control panels and electrical valves and instruments on the equipment skid.

SEI delivered to GA a painted iSCWO skid with all the electrical completed and with all the equipment minus the reactor mounted to the skid frame. GA took receipt of the iSCWO skid from SEI to complete installation of the reactor, the interconnecting piping and to finish the high-pressure welds at the heat exchanger and the reactor inlet and outlet at the GA facilities. GA completed final assembly of the iSCWO system in September 2008. Normally, after completing assembly of an iSCWO system, the iSCWO system would immediately go through checkout and systemization testing followed by demonstration testing; however, the compressor for the Alaska iSCWO system experienced a 6-month fabrication delay so there was no high-pressure air available to test the iSCWO unit. As a result, the Alaska iSCWO system was placed into long-term storage to make room in the GA workshop for the fabrication of another iSCWO unit. The high-pressure air compressor was delivered to GA in April 2009. A process flow diagram (PFD) of the iSCWO process is provided in Figure 1. Photos of the iSCWO equipment skid and the high-pressure air compressor are provided in Figure 2 and Figure 3, respectively.

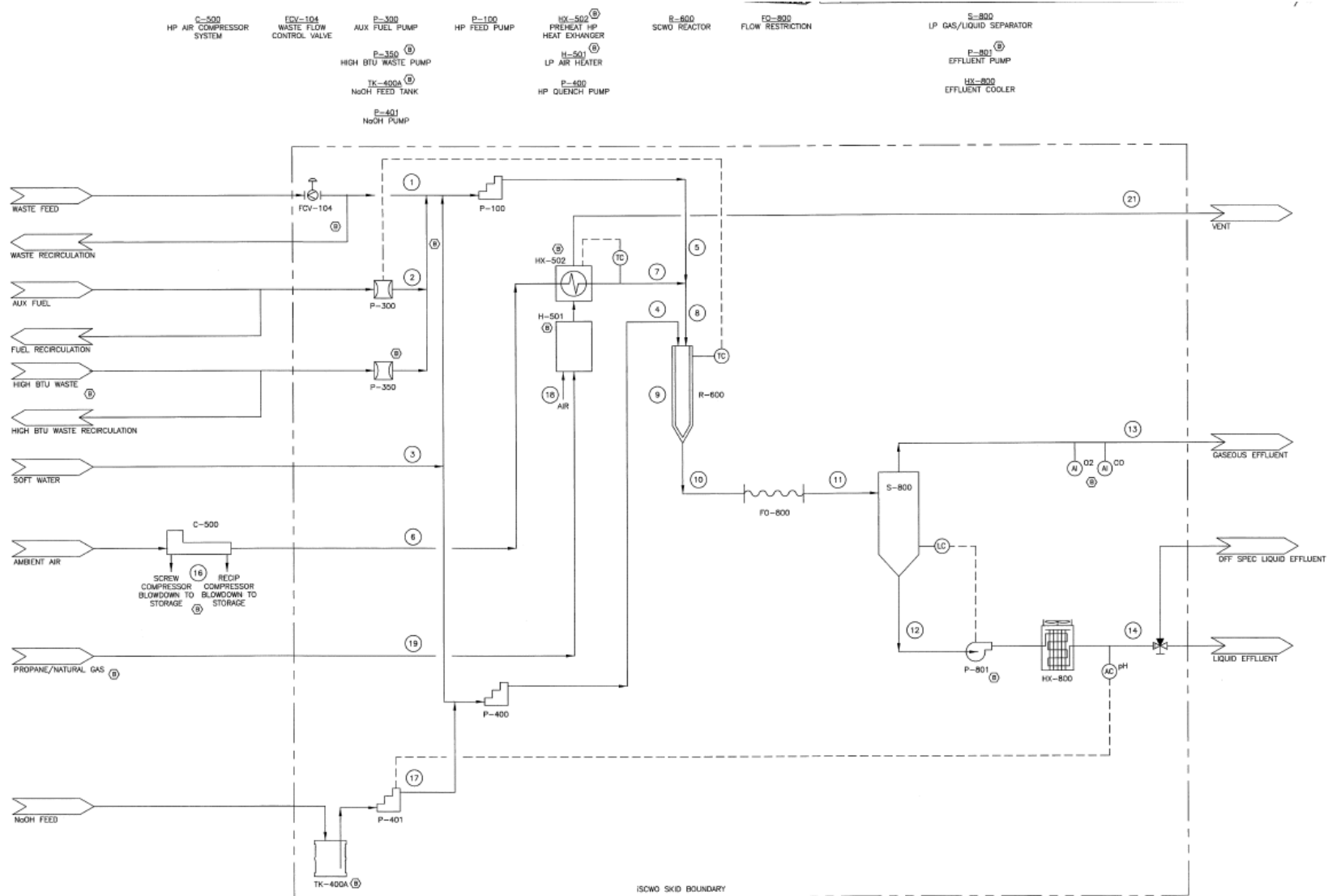


Figure 1. iSCWO Process Flow Diagram



Figure 2. iSCWO Equipment Skid



Figure 3. High Pressure Air Compressor

Checkout testing of the Alaska iSCWO system began in April of 2010 and was completed in June 2010 with a systemization test. During checkout testing of the Alaska iSCWO system, we experienced issues with the high-pressure air compressor. A Greenfield technician was sent out to correct the issue with the compressor. Checkout and systemization testing of the iSCWO system was completed in June 2010. Figure 4 is a run plot summary of the systemization test.

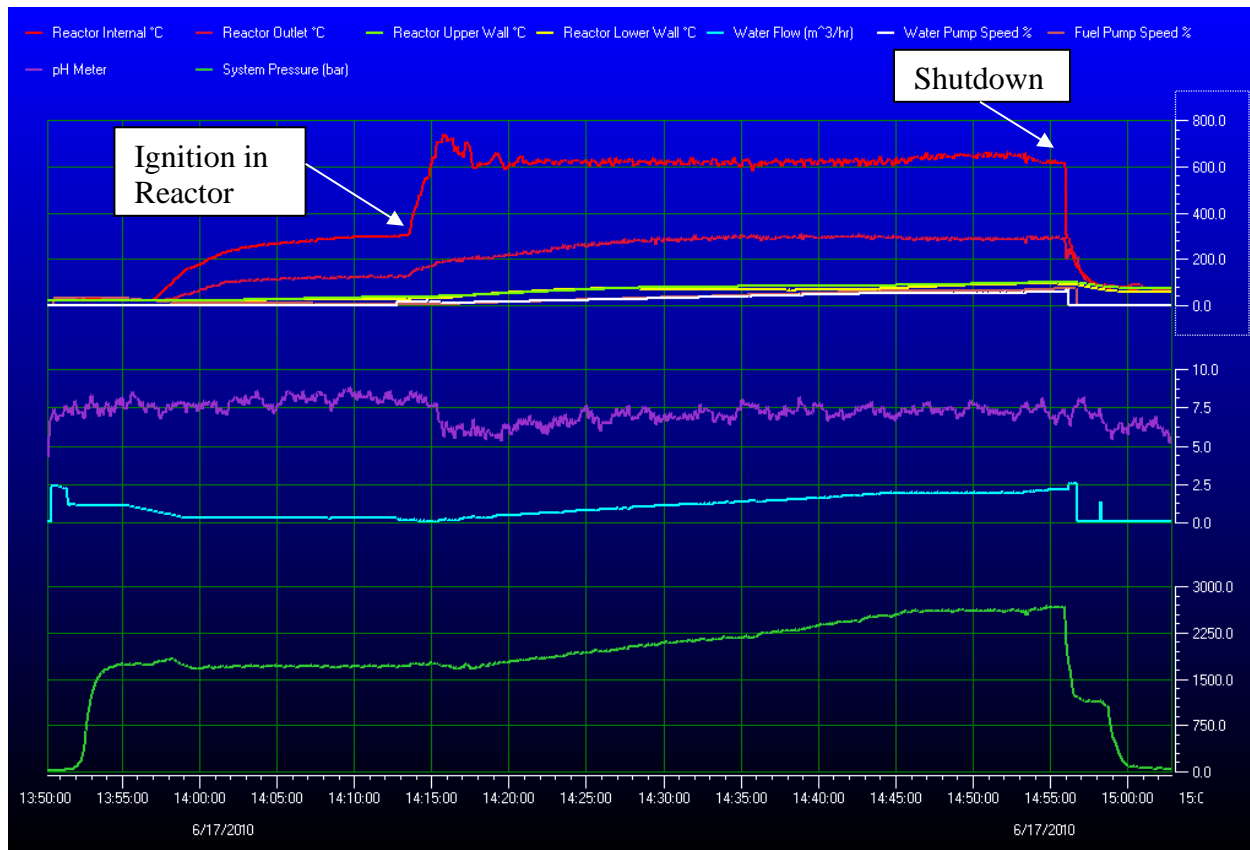


Figure 4. Run Plot Summary for Systemization Test at GA

3.2.2. Waste Survey, Site Selection, and Permitting

Site selection, waste surveying and permitting activities for the Alaska iSCWO system began in October 2006. PENCO took the lead on these three activities because they would be the owner/operator of the waste treatment facility.

3.2.2.1. Waste Survey

Early on in the project, GA and PENCO began a waste survey of all of the hazardous wastes generated in the State of Alaska. The Environmental Protection Agency (EPA) tracks hazardous waste generation and disposal. Alaska does not have a hazardous waste processing facility in the state; as a result, all of the waste generated in Alaska must be shipped via ocean barge to Oregon or Washington where it is off loaded and trucked or transported by rail car to other states for treatment and disposal. The cost of shipment greatly increases the cost of waste disposal, which is passed on to the generators or business owners. In addition to the financial impact of shipping the waste across state lines for disposal, there is also the increased environmental risk of shipping the waste. Transporting the waste via ocean barge from Alaska to the lower 48 states increases the chance for environmental release on the open ocean. By building a treatment facility in Alaska, GA and PENCO want to reduce the cost of disposal and more importantly lessen the chances of environmental release by reducing the transport distances and also the number of instances where the waste is handled by forklift, operators and transferred from trucks or rail cars. The waste survey focused primarily on liquid wastes. It also focused only on wastes that

cannot be recycled or reused. The wastes identified as candidates for iSCWO processing included wastes such as industrial solvents, contaminated oils, contaminated fuels, and mixed liquid wastes. The survey also revealed that the amount of these wastes currently shipped down to the lower 48 states for processing and disposal could completely be processed in a 3-gpm iSCWO system.

3.2.2.2. Site Selection

PENCO had to select and procure a site in Anchorage, Alaska for the waste treatment facility. There are certain land requirements established by the Alaska Department of Environmental Conservation (ADEC) and the EPA that must be met in order to be granted a land use permit and a RCRA permit to build and operate a waste treatment facility. PENCO researched the requirements and after reviewing the list of land available in Anchorage, PENCO determined there was only one viable site to build a waste treatment facility. The site selected by PENCO was zoned for heavy industrial use, was located across the street from the power company and a few blocks from the port and Emerald Services (the largest waste broker in Alaska). The only criteria not met by the property were setback requirements from the street to the building. Based on the dimensions of the property, a newly constructed facility would not meet the required setback distances from the street to one of the outer facility walls. PENCO felt strongly that if the building was properly engineered with additional safety features and spill containment berms, they could apply and be granted an exemption to the setback requirement. As a result, PENCO moved forward with the purchase of the property so that they could begin the application process for a site usage permit and a RCRA operating permit.

3.2.2.3. Permitting

In Alaska, the ADEC grants the land use permit for a RCRA waste processing facility while the EPA grants the construction and operations permit. Before starting the RCRA permitting process with the EPA, PENCO had to first apply and be granted a land use permit from the ADEC.

The application process for the land use permit is a lengthy six-month process. In addition to the formal paper application, there must be a six-month public notice and comment period. A public notice of the permit application is advertised 90 days prior to the first of 3 public meetings. Three public meetings are held in a 60-day period where PENCO and GA present to the public details about the waste processing facility and about the iSCWO technology. Each public meeting is concluded with a question and answer session, which is recorded and moderated by an employee of the ADEC. Questions and concerns from the public are recorded and are formerly submitted with the permit application. PENCO's and GA's responses to the public comments are also recorded and submitted with the permit application. The land use permit application is ultimately reviewed and approved or disapproved by the ADEC commissioner; however, the ADEC commissioner also appoints a five panel advisory committee to oversee the entire application process and to advise the commissioner. The five-panel committee consisted of three members from the community, an employee of the ADEC and also an employee of PENCO. The advisory committee oversees the application process. After the final public meeting, the five-panel committee reviews the public comments and questions from all of the public meetings and they issue a formal request to PENCO asking PENCO to officially respond to all questions and comments made by the public and to any questions posed by the five-panel committee.

PENCO completed all the necessary steps with the land use permit application process with technical assistance from GA as required. According to a letter issued by the commissioner of the ADEC dated October 31, 2007, PENCO submitted a complete application; however, the permit application was denied because the ADEC did not have the authority to grant a variance to the setback requirements for property lines and public right-of-ways per PENCO's request. As a result, PENCO and GA were forced to find an alternative site location for the waste processing facility.

3.2.2.4. Alternative Site Selection

Based on PENCO's earlier site survey, there were no other viable sites to build a waste treatment facility in Anchorage, Alaska. The search for a site then turned its attention to other areas of Alaska. The first area they looked at was the city of Fairbanks. Although not as ideal as Anchorage, Fairbanks would be a viable option because wastes could be transported to Fairbanks from Anchorage via highway and railcar. PENCO found a parcel of undeveloped industrial zoned land 30 minutes outside of Fairbanks in the city of North Pole. This site in North Pole was across the street from a gas refinery and was large enough to meet all setback requirements.

Before deciding whether to buy the property in North Pole it was decided that GA and PENCO would conduct stakeholder meetings with community leaders in Fairbanks and North Pole to present our idea of building a waste treatment facility in their community. GA and PENCO met with the mayor of Fairbanks, the mayor of North Pole, the fire chief of North Pole and also the city council of North Pole to brief them on the design of the waste treatment facility, to introduce to them the iSCWO technology, and to discuss with them the positive economic impact of building a treatment facility in their community. PENCO explained at these meetings that they had not yet acquired the property but were here to introduce ourselves and to gauge their approval or disapproval of building a waste treatment facility in their community. Overall, the meetings with the mayors, the fire chief and the city council went well. They all expressed interest in the project without endorsing the project. They were all excited about the idea of bringing new jobs to the area but they were also cautious over the risks associated with a hazardous waste treatment facility.

Following completion of the first round of stakeholder meeting in August 2010, GA learned that there would be no FY11 funding for the program. As a result, efforts to design, build and permit a waste treatment facility in Alaska were placed on hold. Additional funding was never approved and the initiative to build a waste treatment facility was abandoned.

3.2.3. Systemization of iSCWO System with Advanced Scale Conditioning Agent (ASCA) Simulant

GA was only partially funded to design, build, construct, permit and test an iSCWO facility in Alaska. With the partial funding, GA was able to complete the fabrication of the iSCWO system, but was unable to complete the design, construction and permitting of a hazardous waste facility. Without additional funding, GA decided to discontinue their efforts in Alaska; however, GA still had enough funds to conduct a small demonstration of the iSCWO system. With AFRL approval to change the scope of the contract, GA was able to install the 3-gpm iSCWO system at Explo Systems located at Camp Minden in Louisiana. Installation of the iSCWO system at Explo Systems was completed in July 2012. Explo Systems was also granted a modification to their

existing RCRA permit that allowed them to destroy hazardous waste and energetic materials via SCWO for up to 100 hours of total processing time.

The iSCWO system was initially checkout tested and systematized at GA back in 2010. Installation of the equipment at Explo Systems required that the equipment go through systemization a second time. The iSCWO system was systematized using a simulated waste stream known as Advanced Scale Conditioning Agent (ASCA) simulant consisting of ethylene diamine triacetic acid (EDTA) and ammonia with dissolved metals. Table 5 shows the composition of the simulated waste.

Table 5. Simulant Waste Composition

Chemical Analysis	ASCA Waste Simulant Composition
Measured EDTA (Total EDTA) (g/L)	70.8
Measured EDTA (Total EDTA) (%)	6.4%
Hydrazine (ppm)	<LD ¹
Total Ammonia (%)	0.98%
Iron (g/L)	3.92
Copper (g/L)	4.48
Manganese (g/L)	0.07
Nickel (g/L)	0.05
Zinc (g/L)	0.49

GA successfully processed the simulated waste for 6 hours at steady state flow conditions while maintaining a reactor condition of 700 °C and 3400 psig. Heat-up and ramp up to full flow of diesel fuel, water and air took approximately 51 minutes. Full system flow was approximately 2.5 gpm. Baseline gas and liquid samples were taken prior to feeding ASCA simulant. Ramp up to steady state full ASCA simulant flow took approximately 15 minutes. Full flow of ASCA simulant was approximately 2.3-gpm. The first liquid and gas samples were collected 15 minutes into steady state flow of ASCA simulant, water, diesel fuel and air. Subsequent samples were collected every hour from the start of steady state ASCA simulant flow.

After the sixth hour of steady state flow, an interlock shutdown was deliberately triggered by the iSCWO operator per the run plan. In preparation of the interlock shutdown, the GLS was drained several times of its contents so that all the liquids entering the GLS during the shutdown could be captured and sampled. Figure 5 shows a summary plot of the systemization test running the simulated waste.

¹ LD = Lower Detection

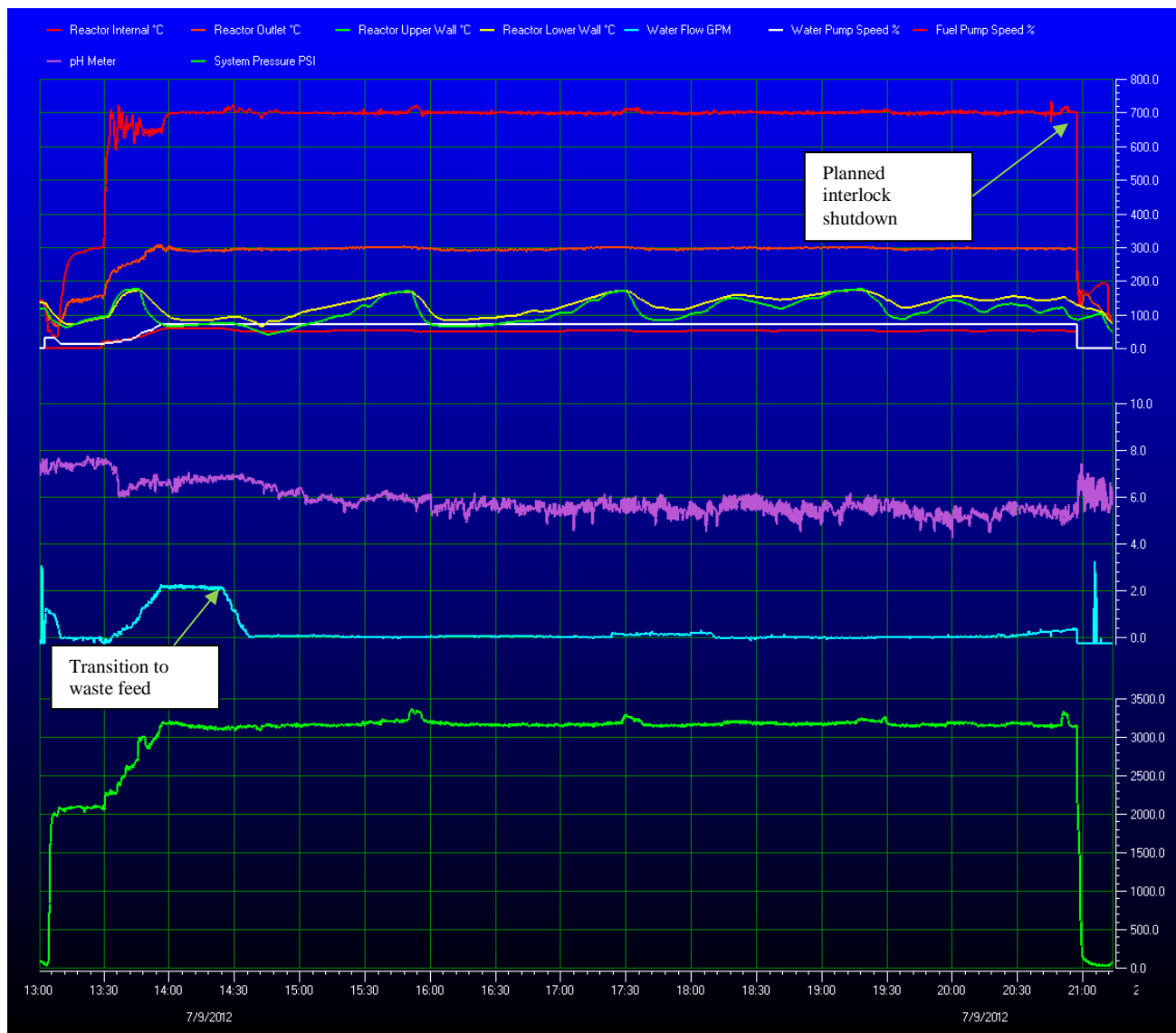


Figure 5. Run Plot Summary for Systemization Test at Expo Systems

Figure 6 shows the appearance of a feed sample (CT2-F0) and seven liquid effluent samples (CT2-L0, CT2-L1, CT2-L3, CT2-L7, CT2-L9, CT2-L10 and CT2-SDL1). The six liquid effluent samples taken during steady state operation are clear with dark brown precipitate settled at the bottom of the bottle. The liquid effluent sample, CT2-SDL1, taken during the interlock shutdown is slightly yellow in color with a dark brown precipitate settled at the bottom of the bottle.

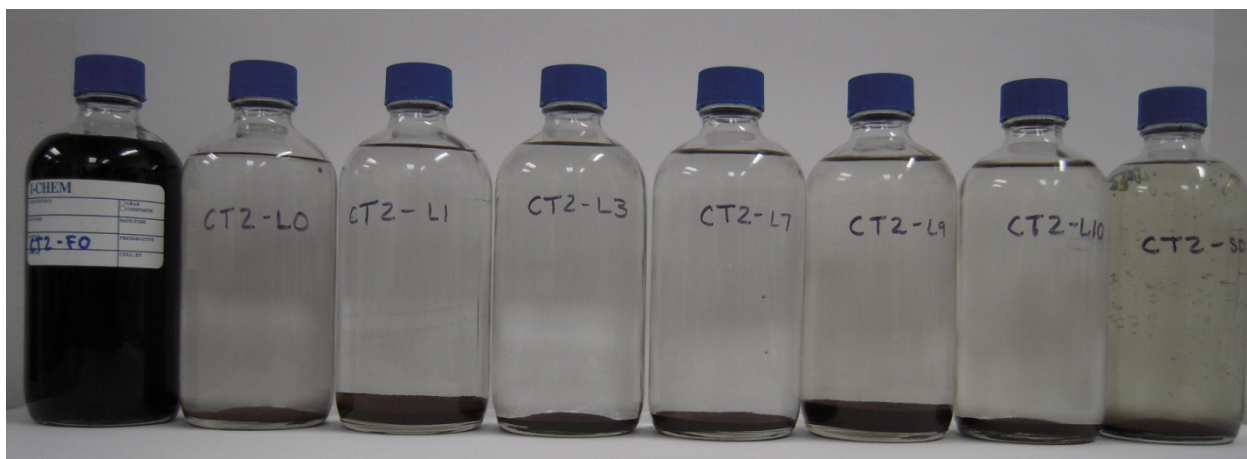


Figure 6. Liquid Effluent Appearance

3.2.4. Demonstration of iSCWO System with Energetics

Following demonstration testing of the iSCWO system at Explo, we began to prepare for energetic waste processing demonstrations. At Explo, we were able to process low concentration waste streams containing ammonium perchlorate (AP), hexachloroethane (HX), ammonium picrate and ammonium perchlorate binder.

3.2.4.1. Demonstration of iSCWO System with AP

GA attempted to process a 10% solution of AP in water on three occasions. The first two attempts were unsuccessful due to interlock shutdowns caused by a loss of instrument air, which were caused by a blown fuse on the instrument air compressor provided by Explo Systems. The third attempted run occurred on August 23, 2012. At the start of steady state waste operations the reactor temperature and pressure was approximately 700 °C and 3400 psig. The CO concentration in the gas effluent was approximately 45 ppm and the pH was 7.1. After several minutes of run time, the pH began to slowly drop. The operator continually increased the NaOH pump output to the quench water to maintain a somewhat constant pH control. It became clear during the demonstration test that the system needed a much higher concentration of NaOH to maintain the pH level during AP testing. The NaOH used during this demonstration test was a 7-wt% solution. Once the pH of the liquid effluent dropped below 3, it was decided to stop the waste feed to protect the downstream equipment from low pH. The system was ramped off AP waste and the system was shutdown. The system maintained steady state waste processing for approximately 91 minutes at an average waste flow rate of 0.37 gpm. Samples of the feed and the liquid effluent were collected and analyzed for destruction of AP

3.2.5. Demonstration of iSCWO System with Hexachloroethane

Following the AP demonstration, GA ran the iSCWO system with a solution of 5.3 wt% hexachloroethane, 27 wt% acetone and 67.6 wt% water. Reactor temperatures and pressures were approximately 675 °C and 3400 psig. The system processed waste for 4 hours. During the 4 hours, the waste flow rate was slowly increased approximately every 60 minutes from 0.7 gpm to 1.55 gpm. In total, we processed approximately 265 gallons of 5.4 wt% hexachloroethane in a water and acetone solution. Table 6 shows the run conditions at various times during the run.

Table 6. Hexachloroethane Summary Run Conditions

	14:21 (Start of Steady State)	15:12	16:26	17:30
Water Flow (gpm)	1.46	1.1	0.89	0.71
Waste Flow (gpm)	0.7	1.1	1.45	1.55
Fuel Flow (gpm)	0.173	0.183	0.094	0.097
Reactor Temperature (°C)	683	675	675	675

Liquid effluent samples from this run were taken and analyzed for hexachloroethane. At the conclusion of this run, an inspection of the reactor nozzle revealed a buildup of material around the tip. After removing the buildup, the nozzle appeared to be in good condition.

3.2.6. Demonstration of iSCWO System with Ammonium Picrate (Yellow D)

Following completion of testing the hexachloroethane solutions, we next attempted to process ammonium picrate in the iSCWO system on October 18, 2012. The system reached steady state at 13:05. Table 7 shows the conditions when steady state was reached while processing ammonium picrate.

Table 7. Ammonium Picrate Run Conditions at Steady State

	13:05	13:35
Water Flow (gpm)	1.09	0.9
Waste Flow (gpm)	1	1.2
Fuel Flow (gpm)	0.226	0.231
Reactor Temperature (°C)	675	675

We began collecting samples in 30-minute increments after the first 15 minutes of running ammonium picrate at steady state. After 30 minutes (13:35), we slowly increased the waste flow from 1 gpm to 1.2 gpm. We continued to run ammonium picrate for a total run time of about an hour and ten minutes at which time we blew a fuse on our iSCWO skid causing a shutdown. Coincidentally, the ammonium picrate feed was almost out and we were about to shut the system down anyways. The system was restarted, ramped back up to pressure & temperature to rinse and flush any remaining ammonium picrate.

3.2.7. Demonstration of iSCWO System with Ammonium Perchlorate Binder

Unfortunately, we were unable to run the AP binder test because of pumping issues. The centrifugal pump used to transfer the AP Binder from the waste tank to the iSCWO unit began to plug almost immediately. GA was in the process of identifying a new pump for AP binder tests when a stop work was issued for iSCWO testing at Explo systems due to Explo's explosive handling license being suspended for improper storage of explosives and energetic materials. Testing was never resumed.

4. RESULTS AND DISCUSSION

As mentioned previously, this contract encompassed two GA technologies. This contract was used to develop the Vitracycle technology and it furthered the research and development of advanced supercritical water oxidation systems. This section will discuss the results from both programs.

4.1. Results and Discussion of the Vitracycle Program

The Vitracycle program resulted in the development of a new GA technology designed to destroy solid wastes. The equipment was designed, fabricated and delivered to GA; however, funding issues prevented the system from being assembled, checkout tested and systematized. Figure 7–Figure 13 show the various components of the Vitracycle system.



Figure 7. Carbon Lance during Factory Acceptance Testing



Figure 8. Vitracylce Reactor being Delivered to GA



Figure 9. Off-loading of Vitracycle Reactor



Figure 10. Reactor Suspended from Superstructure



Figure 11. Genset



Figure 12. Gas Flare



Figure 13. Syngas Compressor

4.2. Results from iSCWO Systemization with ASCA Simulant

The iSCWO system was systematized in San Diego with diesel fuel and water. Gas and liquid samples were not collected; however, the system maintained steady state conditions as shown previously in Figure 1.

The iSCWO system was stored at GA for several years before being relocated and installed at Explo Systems at Camp Minden, LA. Once installed, the system was re-systematized to verify operability of the iSCWO equipment after long-term storage and to confirm that the utilities were connected properly. The systemization test was performed using diesel, water and a simulated waste stream. Liquid effluent samples were collected to verify the destruction of the simulant. Table 8 shows the liquid effluent analytical results from testing.

Table 8. Liquid Effluent Analytical Results Summary

			pH	TOC	Ammonia	EDTA
Sample ID #	Date	Sample Time		mg/L	mg/L	mg/L
CT2-L0	7/9/2012	14:00	8.18	1.1	0.2	ND
CT2-L1	7/9/2012	14:52	6.72	3.6	0.78	0.35
CT2-L2	7/9/2012	15:37	7.44	---	---	---
CT2-L3	7/9/2012	16:37	6.45	2.8	0.7	0.3
CT2-L4	7/9/2012	17:37	6.54	---	---	---
CT2-L5	7/9/2012	18:37	6.56	---	---	---
CT2-L6	7/9/2012	19:37	6.11	---	---	---
CT2-L7	7/9/2012	20:37	6.46	0.97	0.33	ND

The objective of the systemization test was to reach the destruction targets for both ammonia and EDTA. The initial concentration of ammonia in the simulant was 10,841 mg/L and the initial concentration of EDTA in the simulant was 70,800 mg/L. The target goal for the concentration of ammonia and EDTA in the liquid effluent is less than 4 mg/L and 1 mg/L, respectively. All liquid effluent samples collected showed ammonia and EDTA concentrations below the target goal of less than 4 mg/L and 1 mg/L, respectively.

4.3. Results from iSCWO Demonstration with Energetic Feed Streams

The following sections provide results for the energetic analysis of the liquid effluents. The destruction removal efficiency (DRE) was calculated for each iSCWO demonstration. All samples were collected and sent to an analytical lab by Explo Systems Incorporated.

4.3.1. Ammonium Perchlorate

Approximately 33.7 gallons of the 10 wt% AP in water solution was processed during the AP demonstration test. This is equivalent to feeding 27.95 lbs. of pure AP to the iSCWO reactor. Explo Systems collected a liquid effluent sample from the effluent storage tank at the end of the demonstration run and had it analyzed for AP concentration. The lab results showed a concentration of 246 µg/L of AP in the liquid effluent. A total of 912 L of liquid effluent was

collected during the AP demonstration run. As a result, there was approximately 0.00049 lbs. of undestroyed AP present in the iSCWO liquid effluent. Therefore, the DRE of AP during the demonstration run was 99.998%.

4.3.2. Hexachloroethane

The iSCWO system processed approximately 265 gallons of a hexachloroethane, acetone and water solution. A total of 108 lbs. of hexachloroethane was processed through the iSCWO reactor. Explo collected liquid effluent samples during the demonstration run. The last sample collected at 18:06 had a hexachloroethane concentration below the detection limit of $4.1\mu\text{g/L}$. A total of 150 gallons of liquid effluent was collected; therefore the maximum amount possible of hexachloroethane present in the liquid effluent was 5.132×10^{-6} lbs. The DRE of hexachloroethane during the demonstration run was 99.99999%.

4.3.3. Ammonium Picrate

The iSCWO system processed approximately 77 gallons of ammonium picrate solution during the demonstration run. The ammonium picrate solution was 5 wt% ammonium picrate dissolved in near boiling water. A total of 63.7 lbs of ammonium picrate was processed through the iSCWO reactor. Explo collected liquid effluent samples during the demonstration run. The concentration of ammonium picrate in all liquid samples collected was below the detection limit of 0.82 mg/L . A total of 74 gallons of liquid effluent were collected during this demonstration run; therefore, the total maximum amount possible of ammonium picrate present in the liquid effluent was 1.340×10^{-4} lbs. The DRE of ammonium picrate during the demonstration run was 99.9998%.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The Vitracycle technology developed by GA was built but never installed and tested at GA due to insufficient project funding. Without further interest from the AF to develop the Vitracycle technology, GA will not pursue further development of the technology and the equipment will be disposed of per government procedures.

The 3-gpm iSCWO system built for Alaska was eventually installed for demonstration tests at Explo Systems Incorporated at Camp Minden in Louisiana. The system was used to demonstrate SCWO's ability to adequately destroy organics and energetic materials. The iSCWO system successfully destroyed a simulated organic solvent. The iSCWO system was also used to demonstrate the effectiveness of using SCWO to destroy energetic materials. The liquid effluents from demonstration testing were analyzed to confirm energetic destruction and in all cases, the DRE for energetic was >99.99%.

5.2. Recommendations

GA recommends using SCWO technology to treat energetic waste streams. GA also recommends further developing energetic feed preparation and pumping systems in order to make SCWO processing of energetic materials more reliable.

6. REFERENCES

1. Plasma Arc Vitrification/SCWO Waste-to-Energy HMV Engineering Assessment, August 2004, GA Doc. No. 302171902 Rev. NC

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

°C	degrees Celsius
ADEC	Alaska Department of Environmental Conservation
AFRL	Air Force Research Lab
AP	ammonium perchlorate
APET	Asian Pacific Environmental Corporation
ASCA	advanced scale-conditioning agent
EDTA	ethylene diamine triacetic acid
EPA	Environmental Protection Agency
DRE	destruction removal efficiency
g	gram(s)
GA	General Atomics
GLS	gas liquid separator
gpm	gallons per minute
HX	hexachloroethane
IET	InEnTec
iSCWO	industrial supercritical water oxidation
kW	kilowatt(s)
L	liter(s)
lbs	pound(s)s
LD	lower detection
mg	milligram(s)
NaOH	sodium hydroxide
OEM	original equipment manufacturer
PAV	plasma arc vitrification
PENCO	Pacific Environmental Corporation
PFD	process flow diagram
ppm	parts per million
psig	pounds per square inch gauge
PTI	Process Technology Inc
RCRA	Resource Conservation and Recovery Act
SCWO	supercritical water oxidation
SEI	Separation Engineering Incorporated
TOC	total organic carbon
µg	microgram
wt%	weight percent